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The U.S. Army's Land-Based Carrying Capacity

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Introduction

The objective of this technical note is to conceptually frame the Army's requirement for land-based carrying capacity and the capability being developed to address this need. Until recently, research and development (R&D) and technology infusion efforts have approached the carrying capacity need from a logical but "individual pieces" approach rather than from a programmatic perspective. The Army's interest in land management began with a need to manage and sustain the natural resources in its care. The notion of "carrying capacity" arose from the significant overlap between the responsibility to maintain natural resources (environmental stewardship), and the Army trainers' need for well maintained land for use in training exercises. This coincidence of needs has matured the concept of carrying capacity into a comprehensive programmatic approach to land management that yields both environmental and practical benefits.

This technical note will document the problem of land management as related to land-based carrying capacity, and historical efforts to address the problem. This will include the logical progression from exploratory and qualitative research efforts to bound the problem, to the development of more sophisticated and quantitative efforts to determine cause-and-effect relationships. Later efforts have focused on capturing these data and relationships within predictive simulation models. We then describe the various pieces that have been developed, evolved, and experimentally applied, how those pieces fit to become the whole, and how the whole or the pieces can be accepted and used. Finally, we identify short- and long-term knowledge gaps and technical issues that are or will be addressed.

Military Training and Testing Lands Carrying Capacity

Training land carrying capacity is the ability of specific land parcels to accommodate training and mission activity

(U.S. Army 1996). The ability of lands to accommodate and sustain the military mission has been identified as a high priority research requirement (U.S. Army Environmental Center 1996; Andrulius 1994). The Office of the Deputy Chief of Staff for Operations (ODCSOPS) defined the requirement for carrying capacity as: "Installation training managers need to identify carrying capacity of training lands, predict the impacts of land-based usage, understand risk associated with use, analyze decisions to provide training flexibility versus environmental or ecological damage" (U.S. Army Environmental Center 1996). The Office of the Directorate of Environmental Programs (ODEP) defined the requirement for carrying capacity as: "Installation land and natural resource managers need efficient tools, models, and techniques to characterize, integrate constraints, and quantify the capability of DOD lands and natural resources to support the military training and testing missions and other appropriate uses on a sustained basis" (Andrulius 1994).

The issue of carrying capacity first became a requirement for a number of individual installation land managers who had various objectives and perspectives. The term "carrying capacity" was first applied to the military environment in the early 1980s as installation land managers became interested in quantifying increasing demands being placed on limited installation land resources. Many of the early carrying capacity studies were related to the development of environmental impact statements (EISs). As installations began to address these environmental requirements, it became evident that the Army training managers (primary land users) have an interest in land management equal to that of the installation natural resource managers (land stewards). Therefore, any technology developed to address the carrying capacity problem from a perspective of sustaining the training and testing mission must coincide with the way the training community does business. Nevertheless, some aspects of the carrying capacity problem go beyond the requirement to sustain training, and pertain primarily to goals of natural resource stewardship.

Early Carrying Capacity Related Research

An early requirement was to document the magnitude and extent of natural resources degradation caused by military land use activities. A number of studies were conducted to examine and document the cumulative impacts of military training on installation natural resources and to assess the current condition of military lands (Diersing and Severinghaus 1984; Goran et al. 1983; Johnson 1982; Krzysik 1985; Severinghaus 1984; Severinghaus and Goran 1981; Severinghaus et al. 1981; Severinghaus et al. 1979; Severinghaus et al. 1980; Severinghaus and Severinghaus 1982; Shaw and Diersing 1989; Shaw and Diersing 1990; Tazik 1991; Tazik et al. 1992; Tazik et al. 1985; Trumble et al. 1994; Whitworth 1995). These studies often contrasted areas of heavy use with areas of limited or no military training land use, and

documented cumulative impacts of military training activities on vegetation, soils, wildlife, and threatened and endangered species (TES). The studies were conducted at major Army training installations and provided the groundwork for future research on the question of carrying capacity.

These early comparative studies documented the condition of installation lands, and quantified the magnitude and extent of military training activity impacts on installation natural resources. However, information from these studies was not sufficient to adequately model and predict the consequences of future training activities. Because of limitations in study designs, military land use activities were often confounded with other land use activities and environmental gradients. Information on training activities and recovery rates of installation resources was also lacking.

To address these deficiencies, a series of controlled field studies was initiated at several installations. These studies examined changes in vegetation and soil properties resulting from successively higher numbers of passes from military vehicles. The studies were monitored for several years to determine the amount of time required for resources to naturally recover. The first of these studies began in 1986 at Fort Bliss, TX (Brett Russell, Personal Communication) and in 1989 at Fort Hood, TX (Thurow et al. 1995). More comprehensive studies are now underway at Fort Bliss, TX, Orhard Training Area, ID, and Yakima Training Center, WA to quantitatively determine cause-effect relationships on representative land cover types and subsequent recovery times.

A separate but related series of studies involved the development of a natural resources inventory and monitoring methodology. This method has been critical to the assessment of the capacity of military lands to support training, and to the development of predictive carrying capacity models. Knowledge of the current condition of military lands is required to predict the consequences of alternative land-uses scenarios. Monitoring programs also provide validation data to evaluate and improve predictive models.

Research begun in the early 1980s resulted in the development and implementation of the inventory and monitoring program for individual installations and Headquarters, Department of the Army (HQDA) (Diersing and Severinghaus 1985, Severinghaus et al. 1986).

The result of these efforts was the development of the Land Condition Trend Analysis (LCTA) program (Diersing et al. 1992; Tazik et al. 1992; Warren et al. 1990). The LCTA program became the Army's standard for land inventory and monitoring (Technical Note 420-74-3 1990). A number of additional studies have examined the use and extrapolation of survey data resulting from these protocols (Price et al. 1995; Senseman et al. 1995; Senseman et al. 1996; Shapiro et al. 1994; Warren and Bagley 1992; Zhuang et al. 1993; Anderson et al. 1996). Implementation of the LCTA program

has been successfully transferred to the U.S. Army Environmental Center (AEC). However, the U.S. Army Construction Engineering Research Laboratories (USACERL) has continued to support AEC with the improvement of LCTA.

Development of Methods To Assess Effects of Land Use Activities on Installation Natural Resources

Scientist at USACERL have been involved in research efforts since the late 1970s to assess the suitability of parcels of land to support specific land use activities and to predict the consequences of alternative land use. A number of studies conducted between 1979 and 1982 developed qualitative methods to evaluate the potential of military lands to support specific types of nonmilitary land use activities, including off-road vehicle use (Lacey 1981; Lacey et al. 1980; Lacey and Severinghaus 1981; Lacey and Balbach 1980a; Lacey and Balbach 1980b; Lacey et al. 1980; Lacey et al. 1982; Lacey et al. 1979; Lacey et al. 1982; Lacey et al. 1981). Results of these early efforts to predict consequences of nonmilitary land use alternatives were natural starting points for developing assessment methods and predictive tools regarding the capacity of land to withstand training and testing.

Warren et al. (1989) integrated a soil loss model with a geographic information system to create a land classification system. This tool allowed military trainers and land managers to assess the inherent erodibility, current condition, and rehabilitation needs of installation lands. Soil erosion was a quantifiable variable that incorporated many factors that influence land condition; it could also be estimated from currently available data and was easily understood. Erosion modeling is scientifically based and can be estimated using the widely accepted Universal Soil Loss Equation (USLE) and later the revised equation (RUSLE) (Weltz et al. 1987). This methodology provided an objective basis from which military trainers could start to minimize the adverse effects of training on lands by delineating sensitive areas.

This erosion-based land classification system was used in the development of several installation EISs (Balbach et al. 1995; U.S. Army 1994). In the Camp Shelby, MS EIS, estimated soil loss was compared within several proposed maneuver box design alternatives. The analysis provided quantitative information regarding the areas where sedimentation and deposition would likely occur for each alternative. Partially based on the analysis, Camp Shelby was able to support one proposed alternative and develop mitigation procedures for potential erosion problems. In the Fort Lewis and Yakima Training Center (YTC) EIS, soil loss estimation methodology was used to estimate current erosion status and predict the erosion status associated with the proposed alternatives of one and two additional Brigades. These methods provided Fort Lewis and YTC with quantitative information on the potential impacts to soils and soil productivity from alternatives of: (1) no action, (2) one-Brigade training, or (3) two-Brigade

training. The methods also provided a means to predict the distribution of potential impacts so that appropriate mitigation measures could be designed and implemented before implementation of the accepted alternative.

Diersing et al. (1988) extended this erosion-based methodology to include a means to characterize training and predict the effects of various training loads. The methodology also incorporated a qualitative estimate of the recovery. This method was referred to as the Tracked Vehicle Day (TVD) and provided a way to estimate the allowable vehicle use per year that could be sustained indefinitely. Diersing et al. (1990) also developed protocols for incorporating climatic conditions to help limit resource damage by identifying times of the year when lands would be less susceptible to damage by training activities. Shaw and Diersing (1989) demonstrated this model for Piñon Canyon Maneuver Site in Colorado. The model was then applied to other major training installations and provided an initial carrying capacity assessment of military training lands. To improve the model, it was determined that training requirements would need to be integrated into the model.

To accurately predict the impact of training activities on installation resources, training activities needed to be characterized in terms of structure and execution. Balbach and Coin (1984) proposed a conceptual model for predicting military land use demands by vehicle categorization. Diersing et al. (1988) used vehicle characteristics to estimate relative impacts from different training activities.

Guertin et al. (1997) provided a methodology to predict the distribution and intensity of doctrinally based training activities based on historic land use patterns. This methodology was used as part of the carrying capacity methodology used in the Evaluation of Land Value Study (CAA 1996a; 1996b).

Development of Carrying Capacity Models for Upper Level Planning Activities

In 1995, the U.S. Army Concepts Analysis Agency (CAA 1996a; CAA 1996b), with the USACERL's support, completed the "Evaluation of Land Values Study" (ELVS) for the Deputy Chief of Staff for Operations. The objective of the study was to develop an Operation Tempo (OPTEMPO) style cost model for HQDA that could be used to predict the cost of repair and maintenance of training lands in a dollar-per-mile, per-vehicle format. ELVS was a proof-of-concept study to demonstrate a methodology that incorporates the operations and support costs of using land for ground forces training. The methodology incorporates: (1) training strategy, (2) training impact factors, (3) current land condition, (4) a means to predict changes in land condition based on proposed training load, and (5) the cost to repair land to a specified condition. With this methodology, HQDA has the means necessary to assess training land carrying capacity requirements, identify responsible land management practices, and provide resources for these practices all within an OPTEMPO style model (CAA 1996).

In 1996, ODSCOPS funded the Army Training and Testing Area Carrying Capacity (ATTACC) project as a follow-on to the ELVS project to demonstrate, validate, and transfer the ELVS methodology to individual installations (Hunt 1996). The ATTACC project is managed by AEC, USACERL, the Army Training Support Center (ATSC, located at Fort Eustis, VA), Calibre Systems, and Argonne National Laboratory are responsible for executing the project. The methodology is currently being evaluated at 24 training and testing installations.

Current USACERL Carrying Capacity Research

The ELVS/ATTACC methodology essentially consists of these main components: (1) environmental characterization, (2) training characterization, and (3) cost estimation. The environmental component is largely based on a modification of the TVD methodology. The environmental component consists of 4 subcomponents: (1) land condition, (2) training load, (3) a relationship between land condition and training load, and (4) a change in this relationship based on land rehabilitation and maintenance activities (Figure 1).

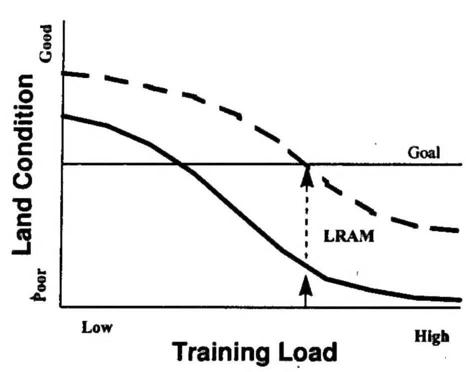

Figure 1. Change in the relationship between land condition and training load based on land rehabilitation.

The modular framework of the ELVS/ ATTACC methodology allows for the rapid development of a working program, while allowing for continual improvements to be made in the future. The results of individual research projects that improve one portion of the model do not require changes to other portions of the model. This framework provides a mechanism to efficiently incorporate research efforts into Army practices.

USACERL's current research efforts addressing the Land-Based Carrying Capacity (LBCC) need are organized within the USACERL business concept of a "capability package." The purpose is to organize our technology outputs into general capability categories or "packages" that are defined to offer the customer or customer advocate an integrated set of technology solutions to systemic problems on the Army installation (USACERL 1995). The individual research projects comprising the LBCC capability package are focused on improving specific components of the ELVS/ ATTACC methodology. Thus the research is primarily focused in the four subcomponents of the environmental characterization component of the ELVS/ ATTACC methodology. The following discussion of our current research efforts builds on the preceding discussion, but is developed within the context of the ELVS/ATTACC methodology.

Erosion-Based Carrying Capacity Models

Results of the early demonstrations of the erosion-based TVD models tended to overestimate erosion status and underestimate the carrying capacity of installation lands. Sensitivity analysis identified several areas for model improvement. The first was the topographic factor of the erosion model (USLE/RUSLE). The USLE was developed primarily for use on agricultural lands that normally exhibit simple topographic features, whereas most natural rangelands, including training lands, exhibit complex topographic features. The second area of improvement was the estimation and extrapolation of the cover factor of the erosion model. R&D efforts were begun to address these weaknesses in the USLE/RUSLE for application to military lands. Mitas et al. (1996) have developed an improved topographic factor (LS) for the USLE/RUSLE model for use on rangelands, including Army training lands. Senseman et al. (1996) have developed an improved method of estimating the vegetative cover factor (C) USLE/RUSLE model. The improved LS factor has been validated with independent data. Efforts are underway to validate both the C and LS factor at additional sites.

Community Dynamics Carrying Capacity Models

Soil erosion status has been the basis for estimating the current condition, carrying capacity, and future condition of training lands (Warren et al. 1989; Shaw and Diersing 1989; U.S. Army CAA-SR-96-5 1996). This is because erosion estimation is the state-of-the-art technology for translating readily available ecological data into a form that is useful to training land managers (DOD 1997; CAA 1996a). Soil erosion and vegetation destruction have been identified as the most common damages that occur on installations (Conrad et al. 1994). However, some installation land managers (among others) have concluded that erosion status alone may not be adequate when addressing all stewardship and installation-specific requirements such as those involving TES habitat (CAA 1996a; Childress et al. 1997).

Current LBCC R&D and demonstration efforts are developing supplemental measures of land condition and predictive models that incorporate these measures. Species composition has been identified as being the next critical measure in addition to erosion status, for assessing land condition (DOD 1997; CAA 1996a). LBCC researchers are working with several Army installations, the University of Texas at El Paso, and Colorado State University to develop and refine a community dynamics simulation model (secondary succession model) for use in determining training carrying capacity on military installations (McLendon et al. 1997; Childress et al. 1997). This work is highly leveraged with other Federal, State, and private agencies with similar land management objectives. A prototype plant succession simulation model has been developed that predicts changes in plant species composition associated with natural

events, land use activities, and military training activities. The model is currently being demonstrated at five major Army installations.

Secondary succession is the process of recovery following disturbance. This process determines patterns and rates of ecological recovery and characteristics of the ecological communities that eventually return to sites impacted by natural or anthropogenic disturbances. Secondary succession also controls the results of revegetation and reclamation efforts. As we develop a better understanding of the process and what controls it, we can significantly increase our ability to restore disturbed sites to pre-disturbance or other target conditions, and we should be able to increase the rate at which we accomplish this recovery.

The primary factors that control secondary succession are climate, colonization dynamics, nutrient cycles, fire, edaphic factors, and herbivory. Each of the six factors is known to be important in controlling secondary succession in at least some ecosystems. However, we are unaware of any other unified studies that investigate all six factors in a series of ecosystems across broad geographical, climatic, and ecological gradients. Such large-scale studies are crucial to establishing and capturing general ecological principles within simulation models.

In addition to the programming and statistical analysis of existing data to build the model, the effort requires literature search, greenhouse, garden plot, and field-scale experiments to quantify mechanisms that control secondary succession under controlled conditions (McLendon et al. 1997; Childress et al. 1997; Thurow et al. 1993). It also requires the establishment of independent field validation plots at each installation. The model is a species-level stress response model that includes the six ecological stressors mentioned above plus the characterization of military training as a stressor.

Within the land management arena and from an ecological perspective, short-term process modeling needs are to continue to select the most important mechanisms that control secondary succession, and to study and quantify these mechanisms across a broad range of climatic, geographical, and ecological gradients. This information is then used to augment and refine the simulation model of secondary succession. To accurately extrapolate the results of the simulation models across a training area or landscape, most installations will need a floristically based vegetation map. Army protocols are now being developed to facilitate this requirement for installations. During FY97, we will be ready to integrate the succession model, the Army refined RUSLE model, and the training use distribution model. We will test the simulation models with independent data to improve their accuracy and apply the models to real installation management problems i.e., proposed future training loads at demonstration/validation scales.

Training Use Distribution Characterization

To fully address the requirement of land capability or capacity of Army training

lands requires representation of the predominant disturbance agent. Army field training activities are comprised of a wide range of tasks depending on the units assigned to an installation. Such activities may include maneuver, live fire, combat engineering, and aviation (AR 25-100, TC 25-1). Of the various activities, mechanized maneuver activities have been identified as a major factor in environmental damage (Conrad et al. 1994). Soil erosion and vegetation destruction are the most common damages (Conrad et al. 1994). Given its importance as a disturbance agent on Army training lands, initial modeling efforts have focused on predicting the patterns of mechanized training.

The objective of the maneuver disturbance modeling effort is to develop a model that will accurately predict the distribution and intensity of maneuver training impacts. If we can realistically simulate impact and distribution of training and testing scenarios, the resulting information can be applied as a disturbance regime into the secondary succession models as well as existing carrying capacity models such as ELVS/ATTACC and TVD. Model results will include the number and distribution of vehicle tracks per unit area over a given period of time and the distribution of multiple tracking within an area.

The approach to develop a maneuver disturbance model is currently focused to meet requirements and restrictions associated with the overall carrying capacity effort. This includes developing a modeling framework that can quickly be adapted to the installations chosen for the successional dynamics model and directly support the ATTACC model for installations. In addition, the effort must be able to succeed given the limited data, funding, and technical resources present at both installation and research levels. Initial efforts have followed research conducted in the area of rangeland carrying capacity, specifically the use of regression models to predict the patterns of distribution of grazing animals (Senft et al. 1983; Bailey et al. 1996).

The model is composed of two major parts: a Disturbance Map and an Event Schedule, brought together to represent overall impacts. The Disturbance Map represents the probability of any particular area of maneuver training land being impacted by vehicle traffic over the course of a year. LCTA disturbance data is used to model training distribution along with other installation data including slope, distance to maintained roads, vegetation cover, training area type, and other spatial features that influence where training occurs (Dubois 1993; Krzysik 1994).

The Event Schedule is a detailed listing of training events that may occur at a particular installation. It consists of a comprehensive list of training exercises and includes information such as unit type and size, number and types of vehicles, off-road miles, and average track width. To date, most of this information has been derived from the ELVS/ATTACC methodology (CAA 1996). The two parts of the model are brought together to produce a series of maps that illustrate the spatial distribution of

training activities. The operation is straightforward. A list of events occurring over a determined time period is compiled. The associated miles and track widths for these exercises are calculated and then distributed across the disturbance maps. Within each unit cell of the GIS maps, the percent area of single versus multiple tracked land is estimated. Currently, training events are assigned to training areas by the operator; plans are being made to automatically distribute events to training areas based on historical use.

Future Direction

The future direction of the training characterization modeling will focus on four major aspects: (1) improved data sources, (2) increased realism in mile allocation within training areas, (3) model validation, and (4) improved modeling techniques. Currently vehicle miles are allocated based on models calibrated with LCTA data. Because LCTA data is "after the fact" evidence of vehicle traffic, problems arise in interpreting the actual land use values. Efforts are now underway to obtain additional data that contain actual location and movements of vehicle traffic. In addition to alternative data sources, we will improve mileage allocation within training areas by identifying more accurate sources of event mileage data. Model validation is an important priority in FY98.

Future R&D and process modeling from an ecological perspective will focus on the following four areas:

1. Continued refinement of successional models until primary mechanisms that control succession are understood and can be accurately simulated. One key area where we have begun research is soil biology, which includes below-ground microbial components as factors. Only limited baseline information is available on the subject as a control mechanism in ecological systems.
2. Physical, chemical and ecological/biological processes do not stand alone, but interact in natural systems. During FY98, we will begin to integrate the interaction of these processes in a realistic way within the simulation models. Refinement of water and wind erosion models and their integration with ecologically based models will be the first step.
3. Most installations include both terrestrial and aquatic systems that interface at wetlands or riparian areas. These systems are not independent and will be integrated in our R&D efforts and simulation modeling efforts under the concept of an ecosystem management approach.
4. Land management simulation models in the future will be incorporated within an easy-to-use modeling environment and user decision support system. We will develop the modeling environment/decision support system around the actual simulation models and user needs, and allow the models, modeling environment, and system to evolve with the technology that will be accepted in common by the users.

This balanced strategy will allow us to focus R&D dollars on the simulation

model development, which represents the science and data needs behind the models and functional integration. We will meet Army needs by focusing only on basic work that most directly meets Army objectives. We will leverage with other agencies and let the academic community pursue the basic work that is of interest to scientists, but that is less directly related to Army needs. The products of our Army-funded basic work will correspond to our applied research efforts and we will demonstrate and validate the products of our applied work at field-scale levels as a coordinated feedback and model validation effort, which will effectively integrate our 6.1, 6.2, 6.3 and 6.4 programs.

Products

During FY97, USACERL plans to begin a demonstration phase for three products. The improved RUSLE equation or soil erosion simulation model (Mitasova et al. 1996) as a product from our Land Rehabilitation and Maintenance capability package. This product will directly support the environmental component of the ATTACC model and will be integrated with the successional model to improve the soil erosion component. From our land-based carrying capacity capability package, the second product to be demonstrated will be the successional or community dynamics simulation model. This model will directly support the ATTACC model to enhance the environmental component, providing simultaneous prediction of erosion, botanical composition, and successional dynamics. The third product, also from the carrying capacity capability, will be the training use distribution simulation model. This model will directly support the ATTACC model by enhancing the environmental component in terms of simulating training distribution and load, and the relationship between land condition and training load. This work will also support the successional model by providing accurate military disturbance information as a major stressor on training lands. Depending on particular Army needs, each of these products can be used as standalone models, as support for the ATTACC model at an Headquarters or installation level, or as an integrated package to support those resource stewardship needs that go beyond the trainer's immediate requirements.

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